LEARNING OUTCOMES

Chapter 1 - Introduction to Flight

Upon completion of this chapter, the cadet should know:
- The relationship between Bernoulli's Principle and Newton's three laws of motion and how they were used to develop a machine that could fly.
- The coefficient of lift and the parameters involved.
- The parts of an airplane and an airfoil.
- The four forces affecting an airplane in flight.
- The three axes, movement around those axes and the control surfaces that create the motion.

Chapter 2 - To fly by the Lifting Power of Rising Air

Upon completion of this chapter, the cadet should know:
- How gliders use the environment to obtain altitude.
- Why gliders look differently than powered airplanes.
- How gliders can achieve great distances without power.

Chapter 3 - Balloons, They Create Their Own Thermals

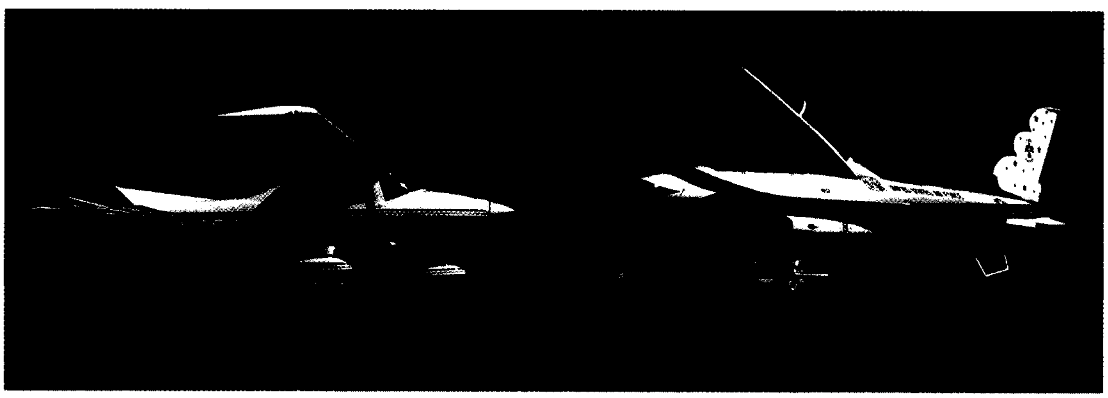
Upon completion of this chapter, the cadet should know:
- The principle of buoyancy and how this relates to the flight of a balloon.
- The components of a balloon and how each works in the flight profile.
- The history of the balloon and why it's recognized as the first powered, manned flight.

WHY AEROSPACE EDUCATION?

We live in a world where every segment of society is affected by aviation and space technology. It is an established fact that America will remain a world leader only as long as we have a strong aerospace program. The United States has always been at the leading edge of aerospace technology and it is the desire of our national leaders to keep us at the front. If we maintain aerospace supremacy, it may very well mean the ultimate survival of democracy and the American way of life.

Shortly after World War II, CAP received its Congressional charter and it is one of the few organizations that still promotes, and understands, aerospace education. The authority for CAP's education and training **mission** is derived from Public Law 476, of the 79th Congress, 2nd Session, which was signed on 1 July, 1946. The law gave purpose and direction to CAP's educational outreach. The challenge was "*...to provide an organization [that will] encourage and aid American citizens in the contribution of their efforts, services and resources in the development of aviation and in the maintenance of air supremacy...*" and to provide "*aviation education and training.*" That challenge still exists to this day!

Aerospace Education is defined as <u>*that branch of general education concerned with communicating knowledge, skills and attitudes about aerospace activities and the total impact of air and space vehicles upon society.*</u> This is a definition every cadet should memorize because it tells us exactly why we study aerospace.



A CAP California Wing Cessna 182 faces an F-16 Fighting Falcon of the US Air Force's Thunderbird flying squadron at the "Thunder Over the Empire Air Fest 2000" at March Air Reserve Base in California.

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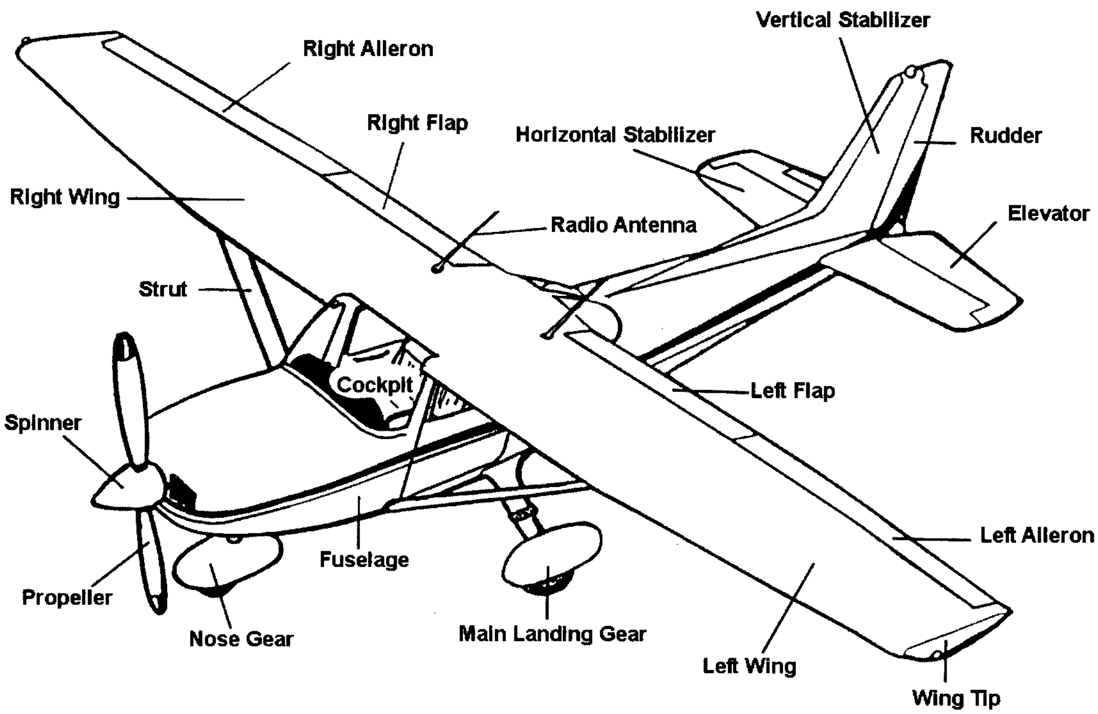
Important Terms - Speaking the Language of Flight

You will find ***Important Terms*** throughout all of the cadet aerospace education volumes. Think of these *terms* as a new "language." To fully understand the science and technology of aerospace, you must learn a new vocabulary. Then, when you are around airplanes, mechanics and pilots, or when you're on an orientation flight, you will be able to "speak *their* language." That is a very rewarding part of the learning process.

Important Terms - Learning The Language Of Airplanes

aero - pertaining to air
aerodynamics - relating to the forces of air in motion
aeronautics - the science of flight within the atmosphere
aerospace - a combination of *aeronautics* and *space*
AGL - above ground level
air - a mixture of gases that contain approximately 79% nitrogen, 19% oxygen and 2% other gases
aircraft - any machine that is capable of flying through the air. Ultralights, airplanes, gliders, balloons, helicopters are all included
airplane - an aircraft that is kept aloft by the aerodynamic forces upon its wings and is thrust forward by a propeller, or other means of propulsion, such as a jet or rocket
airfoil - component, such as a wing, that is specifically designed to produce lift, thrust or directional stability
airport - a place on either land or water where aircraft can land and take off for flight
altitude - height expressed in units above sea level, or ground level
aviation - the art, science and technology of flight within the atmosphere
aviator -a person who operates an aircraft during flight
camber -the curved part of an airfoil that goes from the leading to the trailing edge
chord - a line drawn through an airfoil from its leading to its trailing edge
drag - a force which retards the forward movement of an aircraft in flight
dynamic - forces in motion
leading edge -the front part of an airfoil
lift - the upward force, which opposes gravity, that supports the weight of an aircraft
relative wind - the flow of air which moves opposite the flight path of an airplane
static - standing still, or without motion
supersonic - faster than the speed of sound. Subsonic is below the speed of sound
thrust - the force which moves an aircraft forward in flight
trailing edge - the back part of an airfoil
wind - air in motion



Airplane Components - First, learn the "language" of an airplane!

GODS, ANGELS,PRISONERS AND BALLOONS

Pure mechanical flight involves using some kind of **force** to *lift* a machine upward away from the Earth, thus opposing gravity. A bird is a "living machine" that gets *lift* by flapping its wings. Once airborne, a glider is *lifted* by rising columns of air known as thermals. A balloon is *lifted* by a large bubble of warm air. In flight, an airplane is *lifted* by the dynamic energy forces of the air upon its wings.

From the beginning there have been myths and legends about flying gods, angels and other supernatural beings. One of the earliest recorded accounts of manned flight is an ancient Greek myth that tells of a father and son who were imprisoned on the island of Crete. They decided that the only way to escape the prison was to fly. Secretly, they collected feathers from sea birds and wax from bees to make wings for their arms. When the time came, the father, Daedulus, and his son, Icarus, quietly melted the wax onto their arms and mounted the bird feathers to make wings. When the wax was cool, they started flapping their wings and took off over the Aegean Sea in hopes of reaching freedom.

Daedelus warned his son not to fly too high or the sun would melt the wax on his arms. Icarus was having too much fun and disregarded his father's warning, flying closer and closer to the sun. The heat from the sun eventually melted the wax on Icarus' wings and he plunged to his death in the sea.

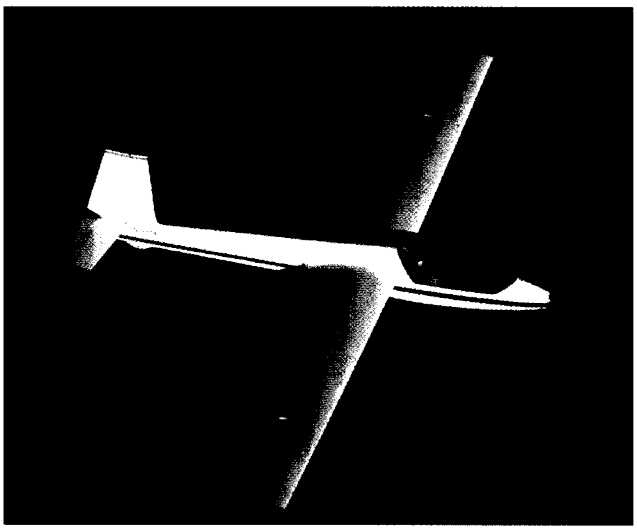
Around 1299 A.D., it was written that the great explorer, Marco Polo, saw Chinese sailors attached to kites being used as military observers.

This could be considered the first "manned aircraft."

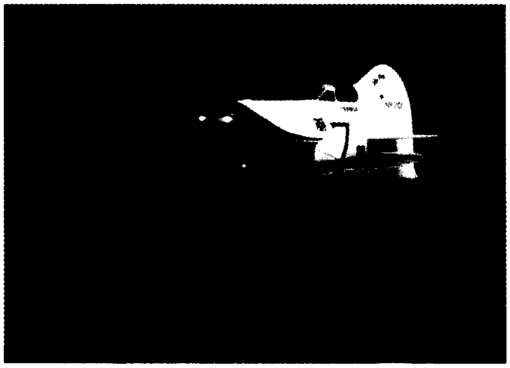
Historians do agree, however, that the first true powered flight, with humans on board, was in a hot air balloon and the event occurred in France during the Eighteenth Century. Brothers, Joseph and Etienne Montgolfier, created a manned hot air balloon. On the November 21, 1783, pilot Pilatre d'Rozier and Francois d' Arlandes, made a historic 25 minute flight over Paris.

Then and Now

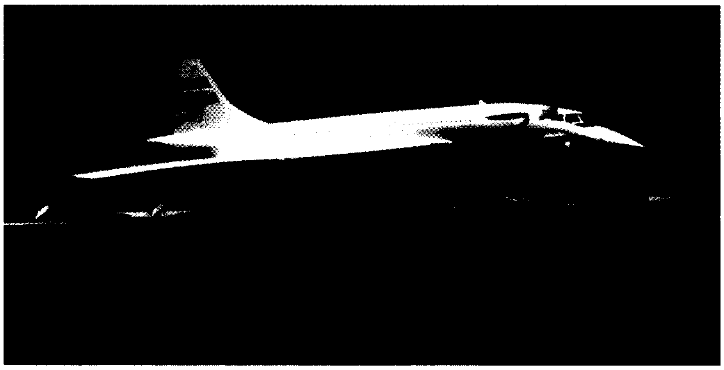
Balloons were the first powered aircraft with humans on board.



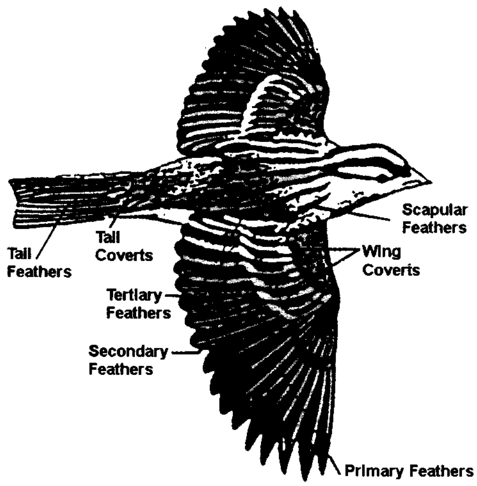
Gliders were the first aircraft that actually had directional control. (*EAA)*

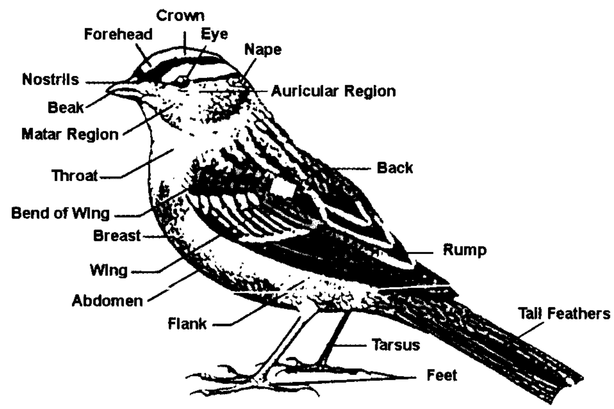


Airplanes evolved around power and propellers. *(EAA)*



Jet engines provide high speed and great reliability. The Concorde, shown here, can carry passengers across the Atlantic Ocean at twice the speed of sound. (*EAA)*





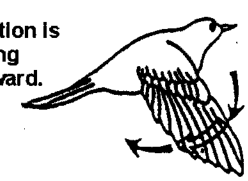
Early man studied birds, watched them fly, and even gave names to their parts...but never quite figured out <u>how</u> they flew!

NATURE'S FLYING MACHINE

In his book ***The Fantasy and Mechanics of Flight,*** Dr. Paul E. Fortin explains how birds fly: *"There are two phases of bird flight — a ground phase and a lift phase. The ground phase allows the bird to get started moving forward in order for the wings to provide the necessary lift. To be lifted by its wings, a bird...must be moving forward fast enough to make air pass over its wings. A bird can move forward by flapping its wings. Most of the flapping is done by the outer wing. <u>The flight feathers work like the propeller of a plane; i.e., they push downward and backward, thereby **driving the air backward** and moving the bird forward</u>. Once the bird's speed is adequate, lift over the wing is generated by the same principle as the flow of air over the wing of an airplane."*

A bird's wing is shaped somewhat like an airplane's wing. The upper surface is curved more than the under surface. Basically, the same principles of lift that apply to an airplane apply to a bird; however, the wings of a bird also act as its propeller. Once again, referring to the Fantasy and Mechanics of Flight, Dr. Fortin says, *"...Slow motion pictures of birds in flight show that the wings move downward rapidly. The wing tips trace a figure eight as they move though the air. The downward beat of the wings moves the bird forward as the outer tips push against the air. Wing feathers are arranged much like shingles on a roof. They change position when the bird is flapping. On the **downbeat** of the wing, the feathers are pressed together so little air can pass through them. **On the up stroke the feathers open."*** The down stroke of the feathers provide a strong lifting force and the opening, upward action provides a smooth energy-saving return motion. You will soon learn that airplane flight is based upon two laws and bird flight utilizes these laws as well.

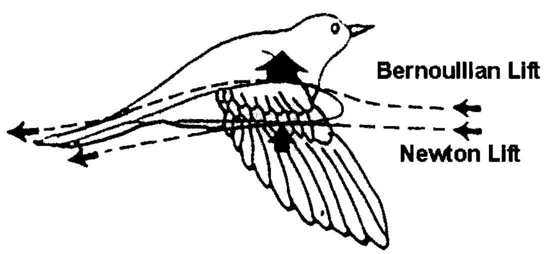
A "propeller-like" thrust action is created when the bird's wing moves air down and backward.



The Lift Phase

The Ground Phase

Like an airplane's wing, there is a pressure difference between the upper and lower areas of a bird's wing. This creates a form of **induced,** or "Bernoullian lift." Also, when the bird changes its body angle slightly upward to its flight path, Newton's third law of motion takes effect and this is an example of **dynamic** or "Newton lift." Like airplanes, birds need to approach and land slowly. A bird uses it tail feathers, and its wing feathers, to steer, brake and produce drag, as well as low speed lift. This greater lift, at a lower speed, allows the bird to land without getting hurt. The bird is a fascinating, natural flying machine and further study into its mechanism of flight, is encouraged. Dr. Paul Fortin's book is highly recommended for Civil Air Patrol cadets, Aerospace Education Members, teachers and students of all ages. The book is available through the Civil Air Patrol Supply Depot at 1-[800] 858-4370.



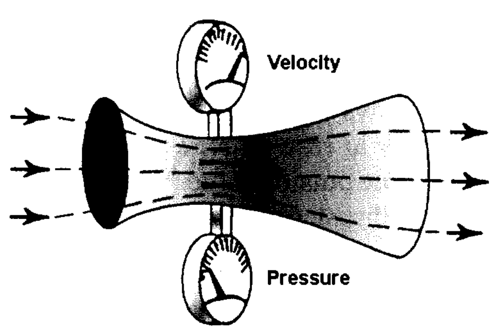
TWO GREAT SCIENTISTS NEVER FLEW, BUT THEY UNLOCKED THE SECRET OF FLIGHT

Although they never attempted to fly, Dutch-born Daniel Bernoulli and Englishman, Sir Isaac Newton, are very important in the history of aerospace. The laws and principles they discovered laid the groundwork for the science of manned flight.

Daniel Bernoulli

Not as well known as Isaac Newton, but certainly one who holds an honored place in the history of aerospace science, is Daniel Bernoulli. His discovery of the relationship between pressure and fluids in motion became the cornerstone of the theory of airfoil lift. He found that a fluid, like air in motion, has a constant pressure. However, when that fluid is accelerated, the pressure drops. Utilizing this principle, **Wings are designed to make air flow go faster on the top**. This in turn causes the pressure to drop and the wing moves upward, against gravity.

Daniel Bernoulli (1700-1782)
Courtesy of The Royal Society, London, England



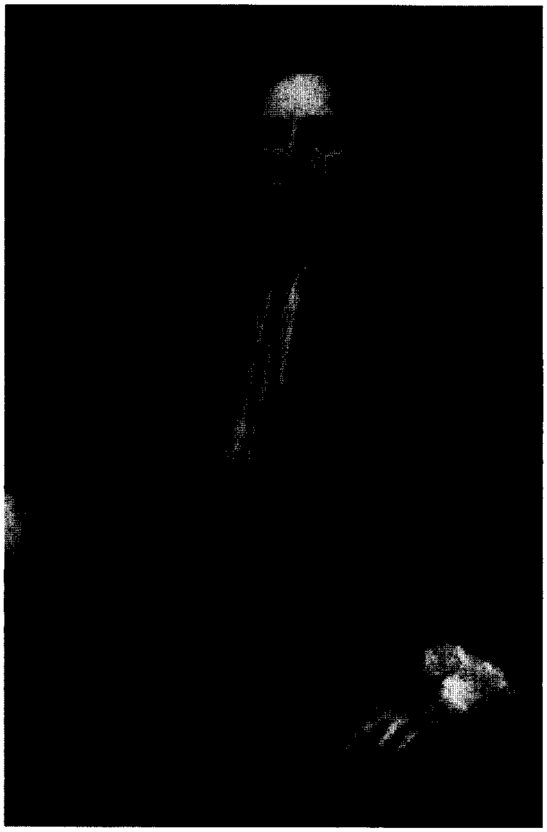
Bernoulli found that the pressure of a fluid, like air, drops when it is accelerated. An example of this can be shown when air passes through a tube that has a restriction. This tube, known as a venturi, causes the air to accelerate when it passes through the middle. The pressure at the restriction drops. Notice the two gauges--the velocity gauge shows an increase and the pressure gauge shows a decrease. This is the secret of flight that eluded mankind for centuries.

SIR ISAAC NEWTON

Isaac Newton received the highest honor when he was "knighted" for his work in science. That is why we call him "**Sir**" Isaac Newton today. He not only gave the world a mathematical explanation of gravity, he figured out how forces and motion are related to matter. He gave the world three laws that are still very much in use to this day:

1. **An object at rest will remain at rest unless acted upon by some outside force.**
2. **A force acting upon a body causes it to accelerate in the direction of the force. Acceleration is directly proportional to the force and inversely proportional to the mass of the body being accelerated..**
3. **For every action, there is an equal and opposite reaction.**

Newton's third law is one of several that is used to explain how an airplane is lifted against the force of gravity. An example of this can be shown by sticking your hand out the window of a car traveling at highway speeds. Point your fingers forward (toward the direction the car is going) with your hand tilted slightly upward, it should rise. The oncoming wind becomes the **action** and the upward movement of your hand is the **reaction**. An airplane's wing acts like your hand. When it is angled slightly upward, it too receives some of its lift from the oncoming air. The airflow is the action and the reaction provides lift.



Sir Isaac Newton (1643-1727) Courtesy of The Royal Society, London, England.

How Do Newton's Laws Work in a Real Airplane?

In the flight of an airplane, both Newton's and Bernoulli's laws work together to provide lift. When the airplane is sitting on the ramp, or runway, it is a body at rest. In Newton's first law of motion, "a body at rest will remain at rest unless acted upon by some outside force." In this case, the outside force is the thrust of the propeller or jet engine. When the thrust, or outside force, moves the airplane down the runway, air flow starts moving over, under and around the wing. Then, as the speed increases, the pilot eventually pulls back on the control yoke, or stick, and the airplane's nose moves upward. The oncoming air impacts the underside of the wing and that's when Sir Isaac Newton's third law helps lift the airplane. The oncoming mass of air is the action and the upward movement of the wing is the reaction.

All three of Newton's Laws of Motion are at work on this *F*-117 stealth fighter. *(EAA)*

How Does Bernoulli's Principle Work on the Real Airplane?

The upper surface of an airplane's wing is designed to have a greater curvature, or camber. This greater curvature causes the oncoming air to flow much faster over the curved upper surface. As the airflow speeds up, the pressure drops on top of the wing and this creates a "suction." Don't forget about Newton's "action-reaction" forces working on the bottom of the wing. This means that there is high pressure below and low pressure above. **With low pressure on top and high pressure underneath, the wing has nowhere to go but up!**

The Mathematics of Wing Lift

The amount of lift produced by a wing can be calculated mathematically. There is a formula aeronautical and aerospace engineers use to make these calculations:

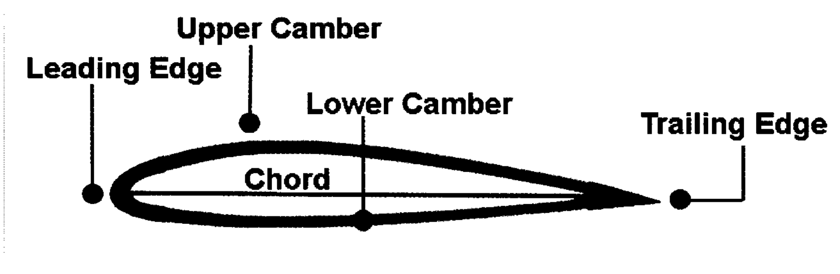
$$\text{Lift} = C_L \times R \times \tfrac{1}{2}V^2 \times A$$

- C_L is the coefficient of lift. It takes into consideration the **angle of attack** and **airfoil design** and is best determined by wind tunnel testing.
- **R** = is the density of the air. Density is defined as mass per unit volume and, the greater the air density, the more lift produced. **Lift and air density are directly proportional.**
- $\frac{1}{2}V^2$ = relates to the velocity of the air over and under the wing. It essentially states that if the speed of the air is doubled, we will get 4 times the lift. In other words, **lift is proportional to the velocity squared.**
- **A** = is the area of the wing. The area is determined by the average **chord** multiplied by the **wing span**. This is much like finding the area of any rectangle and from this formula, it is easy to see that **area and lift are directly proportional**.

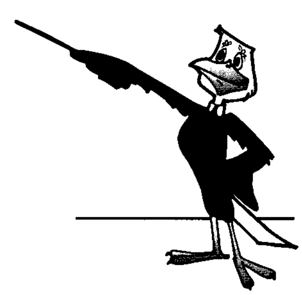
Relative Wind

A wing, creates lift as it moves through the air. Even though the air in the surrounding environment is still and quiet, once the airplane starts to move forward, a wind starts blowing in the opposite direction flowing over and under the wing. This airflow, known as the **relative wind**, accelerates over the curved upper surface, known as the upper camber, and creates an area of lower pressure. The airfoil will then move upward into the low pressure area because the pressure on the underside is higher. The airfoil is literally sucked, and pushed, upward away from the Earth's gravity.

The Language of Wings.



The Cross-section of an Airfoil



The components of a wing can be easily identified in this photograph of a US Air Force Academy TG007 motorized glider. Try and visualize the leading edge, upper camber, lower camber, chord and trailing edge. Notice the great distance from the wing tip to where it attaches to the fuselage, or root. Notice also how small the chord is compared to the length of the wing. The mathematical relationship between the length of the chord and the width of the wing span is called the "aspect ratio." You will see this term used again in the chapter on gliders.

See Activity One - The Lung-powered Wind Tunnel
Refer to the Activity Section at the end of the chapter for this activity.

See Activity Two- Is Bernoulli's Principle Worth Two Cents?
Refer to the Activity Section at the end of the chapter for this activity.

THE FOUR FORCES ACTING UPON AN AIRPLANE IN FLIGHT

There are four forces acting upon an airplane in flight. They are **lift, gravity, thrust** and **drag**. Each of these forces has an opposing force. The word "oppose" means to work against. Therefore, lift opposes gravity and drag opposes thrust. You have already been exposed to these terms, but let's expand them for better understanding.

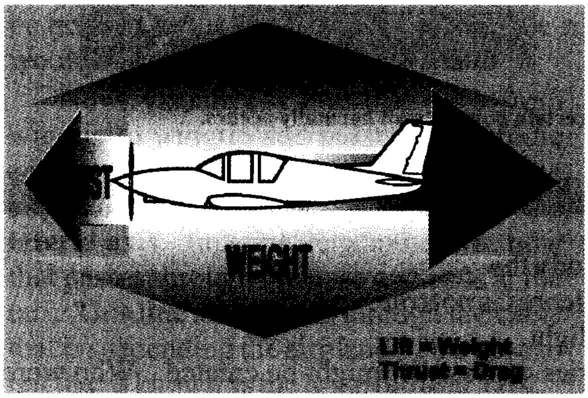
The Two Natural Forces

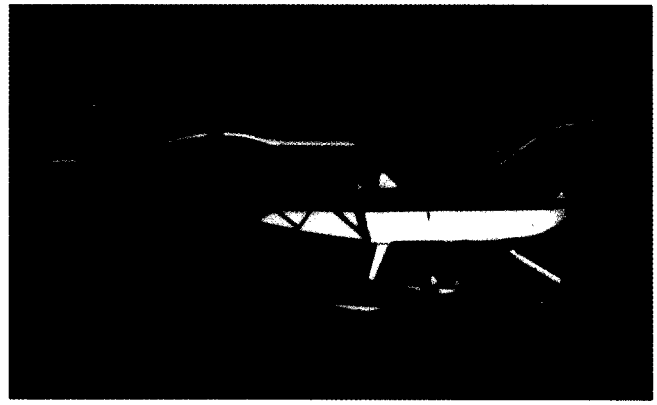
- **Drag** - the best way to understand drag is to imagine walking waist deep in a swimming pool. Now imagine what it's like to walk faster! It is difficult because of the drag of the water on your body. A similar resistance occurs when riding a bicycle against a strong head wind! Like water, air creates drag. Drag is a natural force that is common throughout all of nature.
- **Gravity** - there is a natural force which pulls everything toward the center of the Earth. This is the force of gravity and we speak of that force as being one "G."

The Two Artificial Forces

- **Thrust** - this is a force that pulls, or pushes, an airplane forward through the air and it opposes drag. In some airplanes, thrust is provided by a propeller; in others, it is provided by a jet engine. This force is artificial because it takes a mechanical device, like an engine and propeller, to generate it.
- **Lift** - this is an *artificial force* because it requires a mechanical device to create the pressure changes discussed in Bernoulli's Law. It's pressure differential that creates lift...

not flapping! To put this into practical terms, when an airplane is ready for takeoff, the pilot adds power and the machine moves forward. The relative wind starts to flow under and over the wings. The wings (a mechanical device) are being forced to move through air (a fluid). When the wing is moving fast enough through the air (relative wind) , lift occurs. This lifting force is created artificially.

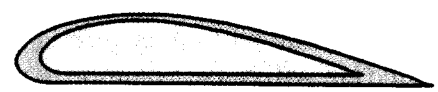




Look at the diagram of the four forces, then imagine you can see them working on the *Vixen*. *(EAA)*

Creating Even More Lift

Over the years since the airplane was first developed, aeronautical engineers found that there are four ways of creating more lift.

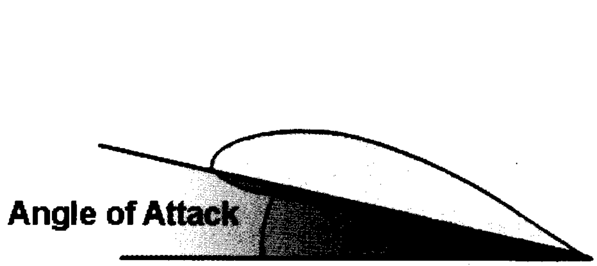


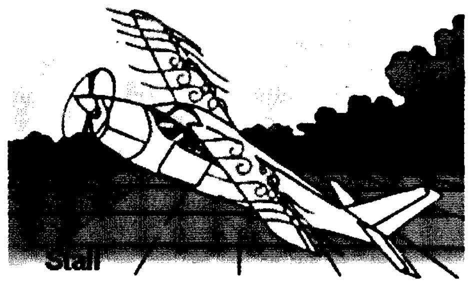
(1) **First a wing will lift more weight if it is larger**. Up to a point, a greater surface area will generate more lift.

(2) **A wing will lift more weight if the upper curvature, called upper camber, of the wing is greater.** You can see that airflow over a greater curvature will have to accelerate to a much higher speed to reach the back of the wing. This causes a greater drop in pressure and more lift will occur.

(3) **By increasing the speed** of the airplane, more lift will occur. This stands to reason because more air molecules are flowing over the wing and air molecules contain energy.

(4) When a wing is tilted upward, it will create more lift because the airflow over the top of the wing again has to travel faster to get to the back. This action is called **"increasing the angle of attack."** The angle of attack is the angle between the chord line and the relative wind. Like size, raising the angle of attack is limited and there is a point where the air flow on top of the wing will separate and start tumbling. This airflow breakaway, from the surface of the wing, creates a loss of lift and is known as a **stall.** For most general aviation wings, this occurs around 17 degrees. The point at which a wing will stall is called its **critical angle of attack.**





When the angle of attack exceeds a certain point, a stall normally occurs.

SEE IF YOU CAN ANSWER THESE QUESTIONS BEFORE GOING ON

1. To understand the "language" of flight, you must study the ______ _______.
2. See if you can name three reasons why the myth of Icarus is not true.
3. What two kinds of lift are experienced by birds in flight.
4. They were great scientists and they gave us theories on how lift might be created. Who were these "giants" in the field of aerodynamics?
5. Can you explain Newton's three laws of motion in aerodynamic terms?

THINGS TO REMEMBER

The "key" to the secret of flight is **FORCE**. Whether it's a bird, a balloon, a sailplane or an airplane, they will all *remain at rest unless acted upon by some outside* ***force!*** A **force**, such as heated air, will cause a balloon to rise. A **force**, such as thermal next to a mountain, will cause a glider to rise, and a **force**, created when the pressure in a stream of air drops, will literally suck the wings of an airplane upward! When a propeller rotates, it creates a relative wind and this in turn creates a **force** that pulls the airplane forward. It doesn't seem like there's much energy in the air, especially in a calm Sunday afternoon breeze; but let that air become a tornado and the power becomes awesome! If the force of the atmosphere is harnessed, it can lift a giant, fully-loaded 747 gracefully into the sky!

Angle of Attack is Used in Several Ways During Flight

The angle of attack is changed many times during the course of a flight. At takeoff, a pilot pulls back on the control (stick or yoke) and this causes the nose to pitch upward, increasing the angle of attack. This is clearly evident in the photograph of the *F*-15. Notice the stabilator, it is fully deflected to cause the airflow to pitch the nose upward and subsequently changing the angle of attack. This also occurs during a landing.

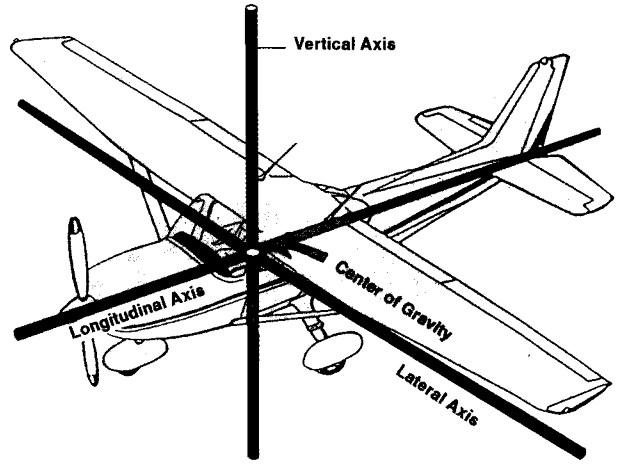
Notice the angle of the aircraft to the runway. If you look closely, you will see this *F*-15's stabilator at full deflection. This is how the pilot makes the nose of the aircraft pitch up on takeoff. This increases the angle of attack and more lift is created. (*EAA*)

THE THREE AXES

Imagine that you are an aeronautical engineer and one of your jobs is to suspend an airplane from a cable so that it will hang perfectly level in all directions. For the sake of illustration, let's say that you are going to do this experiment in a large building area like a hangar or a gymnasium. Somewhere up high, you would hook the cable to one of the ceiling supports. The other end would be hooked to the airplane at precisely the right point where it would hang level. This cable line would be known as its **vertical axis.**

Now, visualize a line that goes from wingtip to wingtip and passes through the center where the cable suspends the airplane; this side to side line is called the **lateral axis**. Imagine yet another line now that passes through the nose and ends at the tail. This line also passes through the cable that is suspending the airplane. This nose to tail line is known as the **longitudinal axis.**

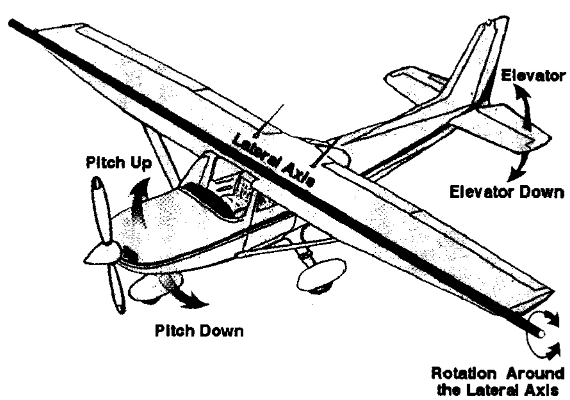
If you hooked your cable at the point where all three of these "axes" come together, that point is called the **center of gravity.**



The Three Axes Of An Airplane

Airplanes Can Only Move In Three Directions

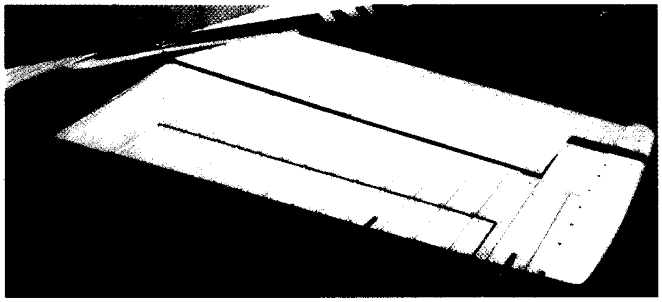
In flight, an airplane can only move in three directions; i.e., nose right, nose left, roll right, roll left, nose up, nose down. Using the example given above, if you walked out to the end of the wing of this suspended airplane and pushed up or pulled down on its wingtip, it would rotate around a different axis. It is called the longitudinal axis. It's a line from nose to tail. Rotation around this axis is called **roll.** If you went back to the tail and moved it up and down, the airplane would rotate around its lateral axis. This motion is called **pitch**. If you moved the tail from side to side, this would be a rotation around the vertical axis and is called **yaw.** Flight is said to be three dimensional. So how does a pilot get the airplane to move in these three dimensions? It's done by using the dynamic forces of the air as they rush over the **control surfaces** of the airplane.



Rotation around the lateral axis is called pitch and the elevator causes this motion. When the elevator moves up, the nose pitches up. When the elevator moves down, the nose pitches down.

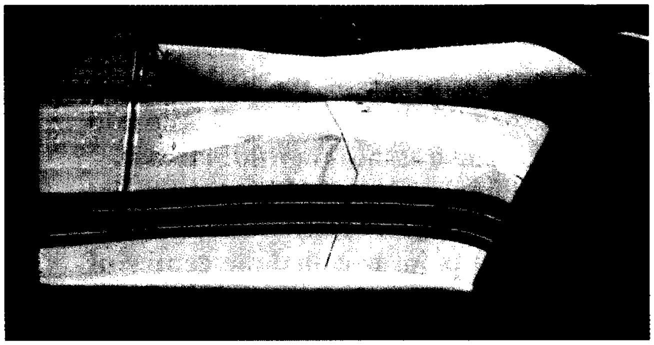
See Activity Three - The Soda Straw Three Axis Demonstrator
Refer to the Activity Section at the end of the chapter for this activity.

The Elevator Is Hinged To the Horizontal Stabilizer



The horizontal stabilizer is fixed and doesn't move. It gives the airplane stability. The elevator is attached to the horizontal stabilizer and moves up and down. Movement of the elevator pitches the nose up or down in a rotation around the lateral axis.

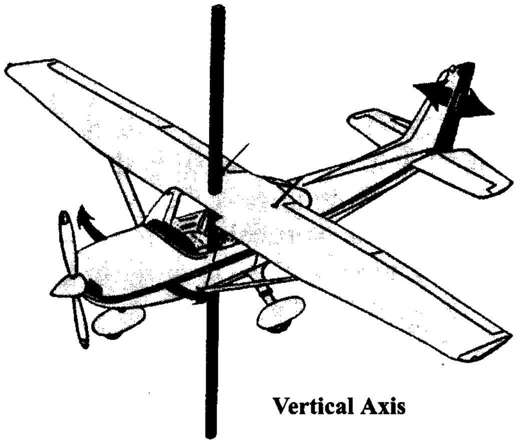
The Stabilator



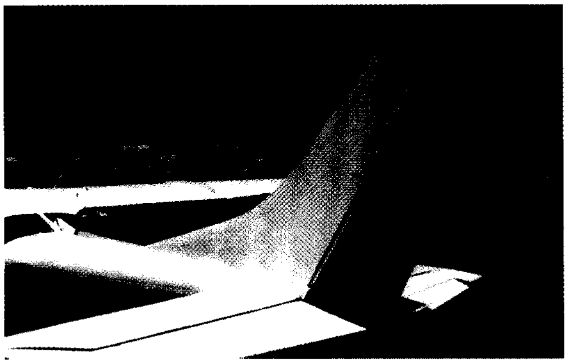
On some aircraft, the horizontal stabilizer and the elevator are one. Engineers call this a "stabilator," and it works by the changing angle of attack. The stabilator is a very effective method of controlling pitch. When the pilot pulls back on the control yoke, the stabilator's leading edge goes down. This creates a "negative" angle of attack and the low pressure increases on the bottom. When the stabilator is moved, it causes a rotation around the lateral axis and the nose is pitched up or down. This was shown in the picture of the *F*-15 at takeoff.

Nose Right, Nose Left

When the pilot wants the nose to go left or right, he/she has to move the rudder pedals located on the floor of the cockpit. When the right **rudder** pedal is pushed forward, this moves the rudder to the right. The dynamic force of the air causes the tail of the airplane to move left and nose will go to the right. This movement is around the **vertical axis**. The nose right, nose left motion is called **yaw.**



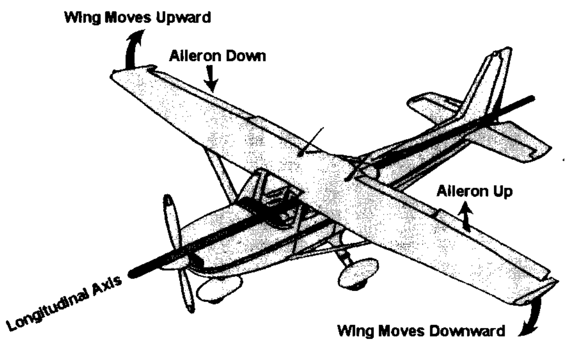
Vertical Axis

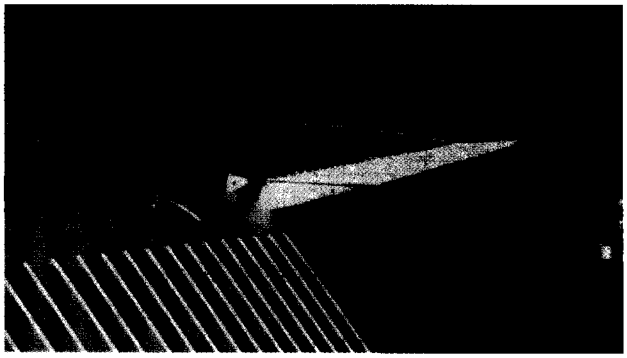


The Rudder on a Cessna *Skyhawk*

Wingtip Up, Wingtip Down

If a pilot wants the wings to move up or down, he/she rotates the control yoke to the right or left. Out on the ends of the wings are located control "surfaces" called **ailerons**. When one aileron moves downward, the other one, on the opposite wing, moves upward and vice versa. The airplane then rotates around the longitudinal axis. This movement around the longitudinal axis is known as **roll.**



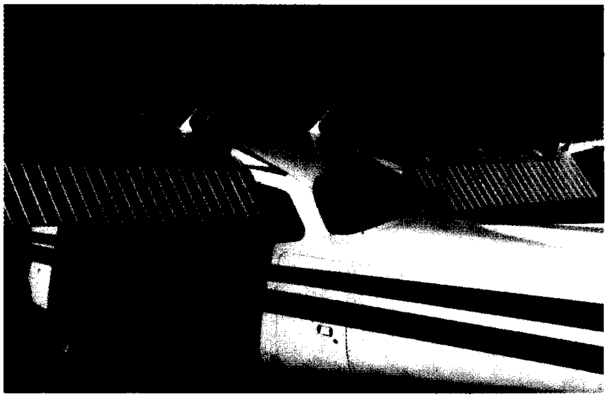


Right Aileron of a Cessna

So, What Are Flaps and What Are They Used For?

When a control surface is moved, especially on a wing, some people will say that the pilot is "moving the flaps." In fact, many uninformed people think that any moveable control surface on an airplane is called a "flap?" So what are the real **flaps** and what do they do?

In the photograph, notice that the trailing edge of the wing is down. It looks somewhat like the whole backside of the wing has dropped. This is somewhat true--the inboard portion of this airplane's wing <u>did</u> go down. From an aerodynamic point of view, study the photograph and visualize the upper camber of the wing, starting at the leading edge and going all the way back to the trailing edge. **With the flaps down, the curvature of the upper camber is dramatically increased and so is the wing area.** The flaps shown on this Cessna are known as Fowler flaps.



The Fowler Flaps on a Cessna *Skyhawk*

When the flaps are down, it causes an increase in both the upper camber and wing area. This will substantially increase lift! So there you have the answer. **The flaps actually increase lift so that an airplane can fly slower and still maintain flight**. Flaps are especially useful in landing where it is desirable to touch the ground at a minimum speed. Flaps are also used during takeoff and this allows the pilot to decrease **takeoff distance**. And finally, **flaps increase drag.** They act like big "doors" that open into the airstream. During one of your orientation flights, ask the pilot to demonstrate the use of flaps. Note the airspeed when the flaps come down. You will also feel a change in the airplane and hear the air rumble around the flaps. The airplane will rise (increase lift) and the wind will buffet (drag) the flaps. They are very effective in what they do!

See Activity Four - Folding, Flying, Controlling the Flight of a Paper Airplane
Refer to the Activity Section at the end of the chapter for this activity.

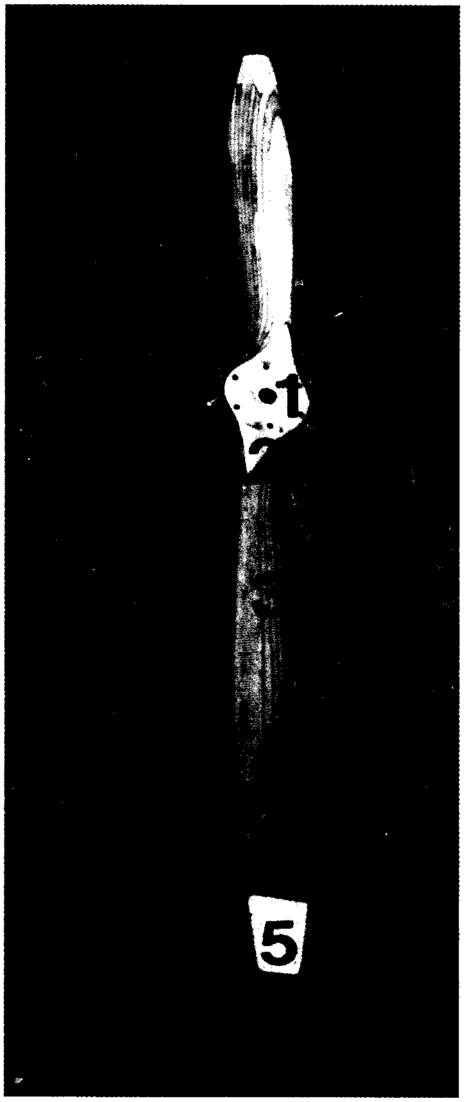
See Activity Five - Build the *SR-71 Blackbird*
Refer to the Activity Section at the end of the chapter for this activity.

THE AERODYNAMICS OF A PROPELLER

When you examine a propeller closely, you soon discover that it is shaped like a wing on each side of the center, or hub. The reason for this airfoil shape is obvious, **it is a wing.** It is a wing designed to "lift" forward creating a force called **thrust.**

As the propeller rotates, its leading edge moves through the air and this motion creates a relative wind. As this rotational relative wind moves around the curved surface of the propeller **blade**, a low pressure is created. This low pressure is a "forward lift," and given enough power, the entire airplane will move forward into this area of lower pressure.

The numbers on the photograph are significant points in the aerodynamics of a propeller. (1) This is the hub. Bolts go through this hub and fasten the propeller to the engine. (2) Notice that this part of the blade is thick and narrow. Note also that the angle, called the angle of incidence, is quite high. If you can imagine this propeller going round and round at a certain speed, other than the hub, this point will be the slowest. Low pressure, or lift, is created by a high angle of incidence and greatly curved camber. (3) Now the blade has a longer chord and greater area. The angle of incidence has slightly decreased and, at this point the speed is much greater. (4) The angle of incidence is considerably less than near the hub. The chord is longer and the speed is higher. (5) Out at the tip, the speed is tremendous so there is a smaller chord, smaller angle of incidence, and a smaller area. If you think in terms of the four methods of increasing lift, the shape of the propeller begins to make sense.



The Propeller Blade

The *P-47 Thunderbolt* had four large "paddle blades" to harness over 2,000 horsepower. The four blades can be seen during this in flight shot! *(EAA)*

REVIEW QUESTIONS

1. Bernoulli's Principle states
   a. For every action there is an equal and opposite reaction.
   b. Force equals mass times acceleration.
   c. The pressure of a fluid, when accelerated, increases.
   d. None of the above is correct.

2. Sir Isaac Newton gave us three laws of motion. Which one applies to an airplane in flight?
   a. For every action there is an equal and opposite reaction.
   b. A body at rest will remain at rest unless acted upon by some outside force.
   c. A force acting upon a body causes it to accelerate in the direction of the force. Acceleration is directly proportional to the force and inversely proportional to the mass of the body being accelerated.
   d. All of the above are correct.

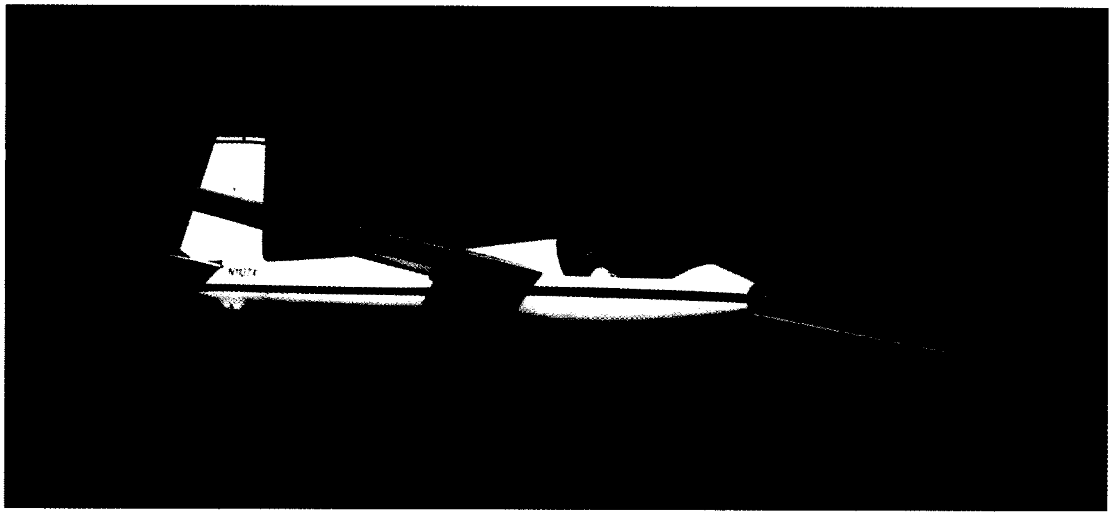
3. When the angle of attack reaches a point where it will stall, this is called
   a. the critical angle of attack.
   b. the stall point.
   c. Bernoulli's Dilemma.
   d. the lateral axis.

4. Match the following motion to its proper axis
   a. Motion about the lateral axis is roll; motion about the vertical axis is pitch and motion about the longitudinal axis is yaw.
   b. Motion about the lateral axis is pitch; motion about the vertical axis is yaw; and motion about the horizontal axis is roll.
   c. Motion about the lateral axis is pitch; motion about the vertical axis is yaw; and motion about the longitudinal axis is roll.
   d. Motion about the vertical axis is yaw; motion about the longitudinal axis is pitch; and motion about lateral axis is roll.

5. Some airplanes are equipped with Fowler flaps. These go outward and downward. This causes
   a. wing area to be decreased and camber to be increased.
   b. wing area to be increased and camber to be increased.
   c. wing area to be decreased and camber to be decreased.
   d. zero drag.

6. Which part of a propeller has the highest rotational speed?
   a. the tip
   b. the hub
   c. the angle of incidence
   d. the turbine

2 TO FLY BY THE LIFTING POWER OF RISING AIR



(EAA Photograph)

Important Terms - The Language of Sailplanes & Gliders

altitude - the height, or distance, above a reference plane. The most common planes of reference used in aviation, are heights above sea level and ground level. If it's above average sea level, it's referred to "MSL," or *Mean Sea Level,* and if it's *above ground level,* it's referred to as "AGL."
aspect ratio - The ratio between the span of the wing and the chord length.
convection - fluid motion between regions of unequal heating.
density - mass in a given volume. (Example 12 eggs in a basket).
glide ratio - a mathematical relationship between the distance an aircraft will glide forward to the altitude loss. If an aircraft has a glide ratio of 20 to one, and it is one mile above the Earth, it should glide 20 miles before landing.
lapse rate - the average rate at which temperature decreases with an increase in altitude. The average lapse rate is 3 ½ $^{\circ}$F per 1000 feet increase in altitude.
lift-to-drag ratio - this ratio is used to measure the gliding efficiency of an aircraft. The angle of attack that results in the least drag will give the maximum lift to drag ratio, the best glide angle and the maximum glide distance.
soaring - the art of staying aloft by exploiting the energy of the atmosphere.
span - the distance from wingtip to wingtip.
spoilers - devices located on the wings that disrupt the airflow over the wing. This disruption causes a loss of lift. They can also serve as air, or dive, brakes.
stability - the atmosphere's resistance to vertical motion.
thermal - a column of air that moves upwards.
tow plane - usually, a single-engined airplane that will pull a glider from the ground to an altitude where it can be released.
wave - As air moves across mountain ranges, it sometimes starts a waving action with strong up and down motions. Sailplane pilots can use the motion of this wave to gain altitude.

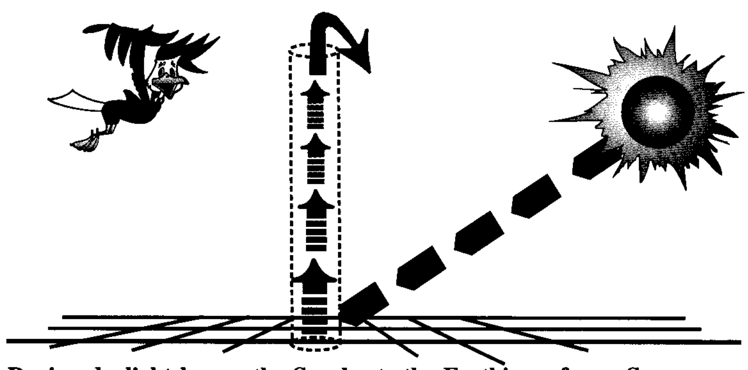
RISING AIR CAN MAKE THINGS FLY

Rising air can have enough energy to provide lift for an aircraft. That's what soaring flight is all about. Normally, we think of air moving parallel to the Earth and of course, we call this "wind." But, there are other factors involved and one of the most important is the influence that the Sun has upon our environment. From 93,000,000 miles away, it provides energy that causes our atmosphere to move both **horizontally** and **vertically**. This vertical motion provides lifting power for sailplanes.

When the surface of the Earth gets warmed by the Sun, the surrounding atmosphere is heated and this causes the air to rise. This vertical motion happens because of a change in the density of the air. As the air becomes less dense, it tends to get lighter and this lighter air wants to rise upward until it cools. This cooling with an increase in altitude is called the **lapse rate**. Normally, the temperature will drop at a rate of 3 ½ ° F for every 1000 feet of altitude gained. The Celsius equivalent of this is 2° C per 1000 feet of altitude.

When warm air rises into the colder air at higher altitudes, it cools and then stops rising. After a period of "hanging around," the air begins to sink back toward the Earth. This up and down movement results in a circulation known as convection. Sometimes the atmosphere strongly resists this convective circulation and is said to be **stable**.

Two other things happen to air when it is heated, it expands and the pressure drops. Here's an example: In early morning, the air is cool due to low overnight temperatures. The molecules are close together and the atmosphere is more dense when it is cold. When the Sun comes up, it warms the Earth, and this warms the surrounding atmosphere. The molecules start bouncing around at a higher rate due to heat energy. Because they are bouncing around faster and faster, they spread out. This means any given parcel of warm air will be lighter than an equal parcel of cold air. As a result of a decrease in density and a lighter weight, the warm air rises. This upward flow has energy in it and given enough power, it can lift a flying machine!

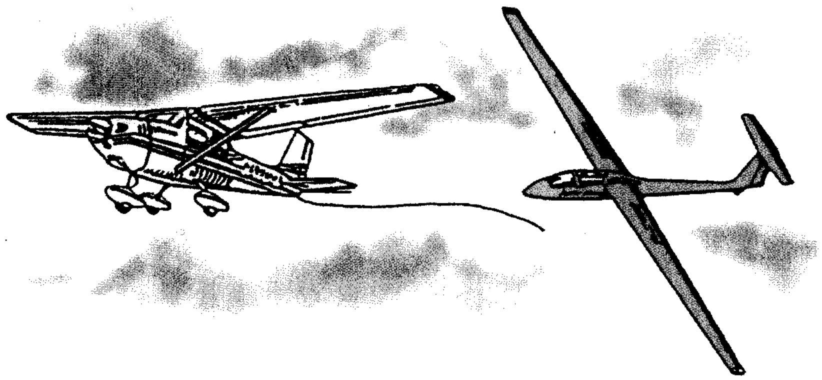


During daylight hours, the Sun heats the Earth's surface. Some areas absorb this energy while others tend to reflect it back into the atmosphere. This reflected energy heats the surrounding atmosphere and causes rising columns, or even bubbles of air called thermals. It's these thermals that provide lift for sailplanes.

GLIDERS AND SAILPLANES - Aircraft Designed to Ride the Rising Air

When the air moves upward, it can provide enough lift to keep a competition sailplane up for hours. By technical definition, a glider is an aircraft that is towed to a certain altitude and then it glides back to Earth due to the pull of gravity. A sailplane, on the other hand, actually soars on the energy of the environment. The pilot of a sailplane uses every method possible to find lift and then to ride it to a greater height.

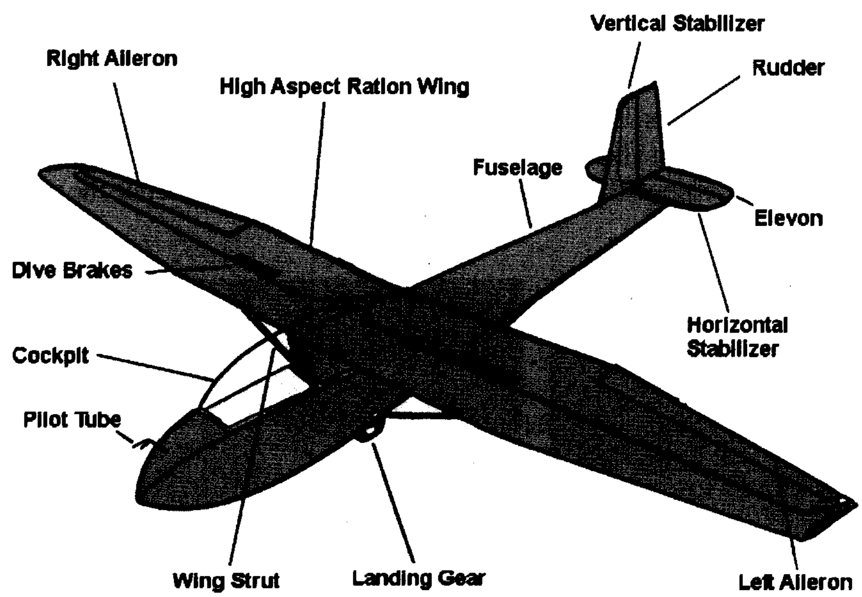
During World War II, the Allies used gliders to haul soldiers into battle. They were towed aloft by transport airplanes and then released over designated drop zones. Once released, the skilled glider pilots would try to get it safely back on the ground so the troops could be in a better combat position. In later wars, the glider was replaced by troop-carrying helicopters and this proved far more effective in the combat environment.



After being towed to altitude by a powered aircraft, modern sailplanes are released. The sailplane pilot searches for rising thermals in the atmosphere and these provide lift.
(Illustration by Dekker Zimmerman.)

The United States Air Force Academy Sailplane

It is the dream of many CAP cadets to someday enter the United States Air Force Academy in Colorado Springs, Colorado. One of the outstanding programs at the Academy is their sailplane training and many cadets get the opportunity to take flight training in a *Schweizer TG-4A* sailplane.



The dimensions of the *TG-4A* are: length 25 feet, 9 inches; span 51 feet; height 9 feet, 3 ½ inches; wing area 219.48 square feet; Aspect ratio 11.85:1. The maximum gross weight is 1,040 pounds and glide ratio is 23:1.

The sailplane has dual flight controls. The flight control surfaces are actuated by control sticks and rudder pedals through a push rod and cable system. Aileron and elevator control is accomplished through push rods connected to both control sticks. Rudder control is accomplished through cables attached to both sets of rudder pedals.

The USAF Academy *TG-4A* sailplanes are equipped with some instruments which include an airspeed indicator, an altimeter, a vertical velocity indicator, a sensitive variometer and compass.

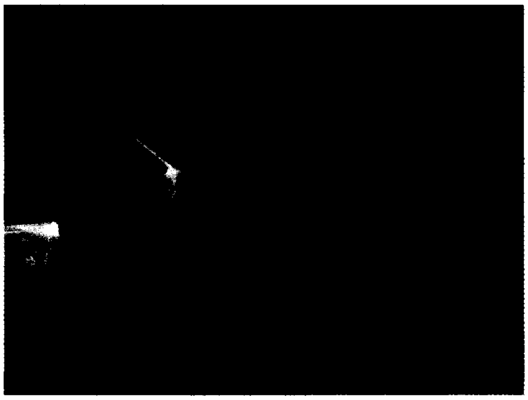
See Activity One - Build An Air Force Academy *TG4-A* Glider
Refer to the Activity Section at the end of the chapter for this activity.

Academy cadets preparing the *TG-4A*s for another flight.

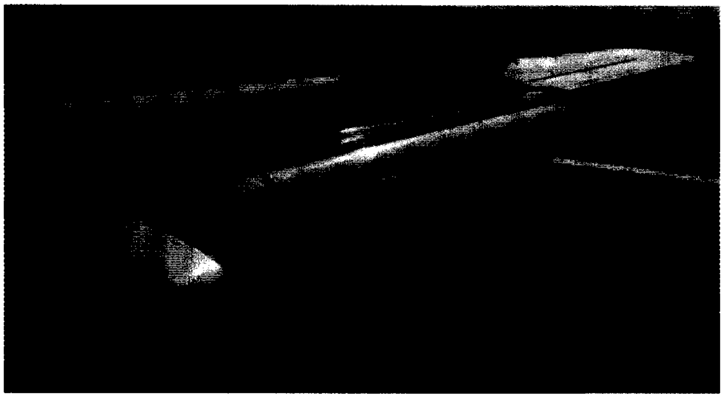
Cockpit of a *TG-4A*

Something Different - Spoilers

Aside from the engine and propeller missing, there are a few other differences between a sailplane and a conventional airplane. On the wings of most sailplanes, and a few high performance airplanes, you will find lift spoilers on the upper surface. On the *TG-4A,* they are called **divebrakes**, but the more conventional term is **spoiler**. The purpose is to disrupt airflow over the upper camber of the wing. This causes a loss of lift and an increase in the rate of descent. In a steep angle of descent, they can also be deployed as brakes, hence the word "dive brake."



Dive brakes, or spoilers, on the *TG-4A*



The spoilers have been deployed after landing on this Boeing 737. They keep the airplane on the ground and help slow it down.

If you happen to have a window seat behind the trailing edge of the wing on an airliner, you may get a chance to see the lift spoilers in action. These are used in flight, along with the ailerons, to roll the airplane around the longitudinal axis. On the ground, after landing, the spoilers help keep the airplane on the ground by spoiling lift and acting as air brakes.

REVIEW QUESTIONS

1. The most significant reason why air rises within the environment is
   a. the Sun.
   b. changes in air density.
   c. pressure decrease.
   d. wind.

2. The ratio of the wingspan to the wing chord is known as
   a. lift to drag ratio.
   b. glide ratio.
   c. aspect ratio.
   d. lift ratio.

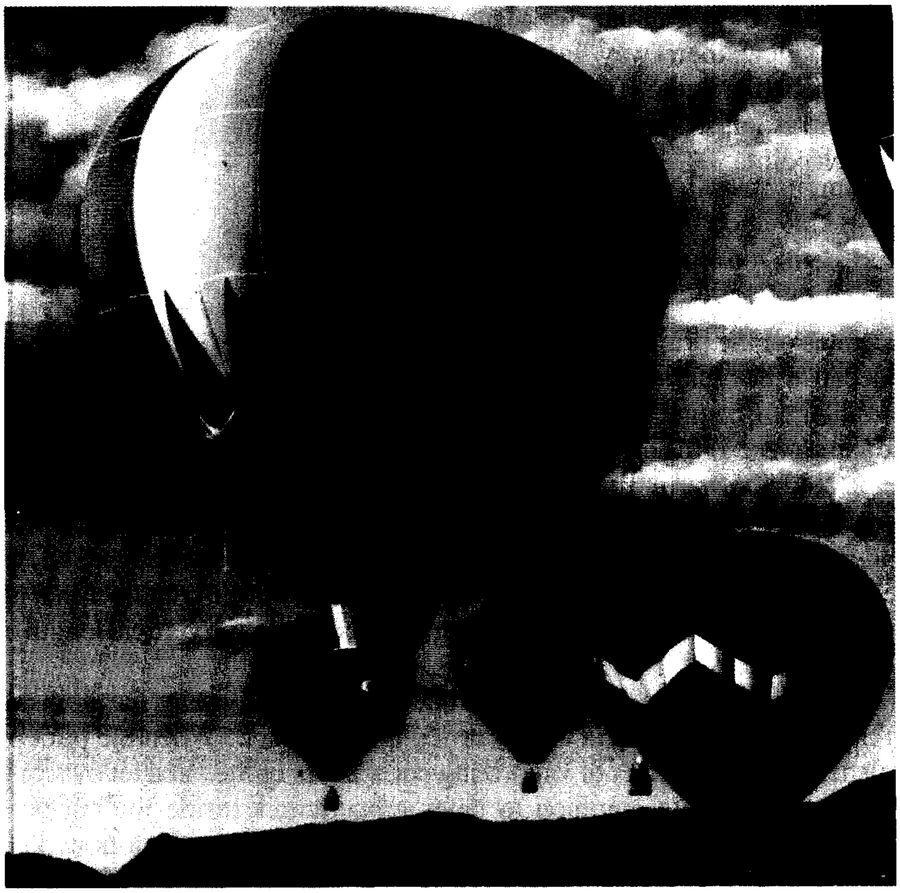
3. When a glider comes within a few feet of the Earth's surface, it has a tendency to want to keep flying. This phenomenon is known as the **Ground Effect**. Glider pilots have a device that enables them to overcome this tendency to "float" and to execute a landing. The device is
   a. horizontal stabilizer.
   b. flaps.
   c. tow hook.
   d. spoilers.

4. The mathematical relationship between the distance an aircraft will glide forward to the altitude loss is known as
   a. glide ratio.
   b. aspect ratio.
   c. lapse rate.
   d. adiabatic lapse rate.

5. As air moves across a mountain range, it sometimes starts an up and down motion. Glider or sailplane pilots use this motion to gain altitude. It is called
   a. lapse rate.
   b. convection ratio.
   c. wave.
   d. altitude ratio.

7. Air in motion is called
   a. wave.
   b. thermal.
   c. wind.
   d. Technically, all three are correct, but the most correct answer is "c."

5 BALLOONS - THEY CREATE THEIR OWN THERMALS

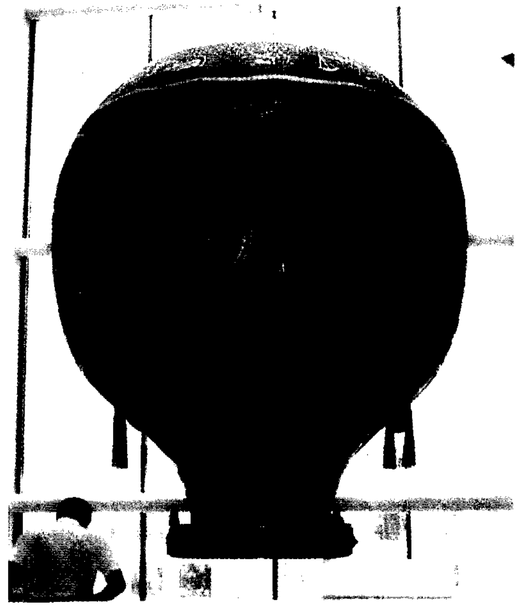


Important Terms - Balloon Language

balloon - an aircraft that uses lighter-than-air gas for its lift. This craft has no built-in means of horizontal control.
burner - the heat source for filling the envelope with hot air
buoyancy - to rise or float on the surface of water or within the atmosphere
crown - the top of the hot air balloon's envelope
envelope - the main body of the balloon usually made of nylon
gore - one of several vertical panels that make up the envelope
Montgolfier - the name of the two French brothers who created the first successful, manned, hot air balloon in 1783
parachute panel - located in the top of the balloon's envelope that allows it to be deflated. When a larger area of deflation is needed, some balloons are equipped with a rip panel.
propane - a lightweight, low carbon fuel used in hot air balloon burners
thermistor - an instrument which measures the temperature within the envelope
wicker - a form of wooden construction used in the baskets (gondolas)

BALLOONS WERE FIRST

It was not until November 21,1783, that a successful manned, powered flight was made. That monumental event took place in a hot air balloon. Two Frenchmen, Pilatre d'Rozier and the Marquis Francois d'Arlandes, flew their way into history aboard a balloon launched in Paris. The flight lasted about 25 minutes and it landed approximately five miles from the launch point.



A replica of the Montgolfier balloon is on display in the US National Air and Space Museum.

How They Fly

A balloon operates on the principle of buoyancy. It all happens because hot air is lighter, or more buoyant, than cold air . Imagine that you have two parcels of air the same size. If the air in one parcel is hot and the other is cold, the warm-air parcel will be lighter. If you could insert the hot parcel of air inside of a very lightweight balloon, it would rise into the surrounding colder air. With enough hot air, a balloon will lift not only itself, but passengers, instruments, fuel and all of the equipment needed for a flight. The large container that holds this hot air is called the envelope. There are strips of very strong material along the vertical length of a balloon that attach the envelope to the basket. These are known as load tapes.

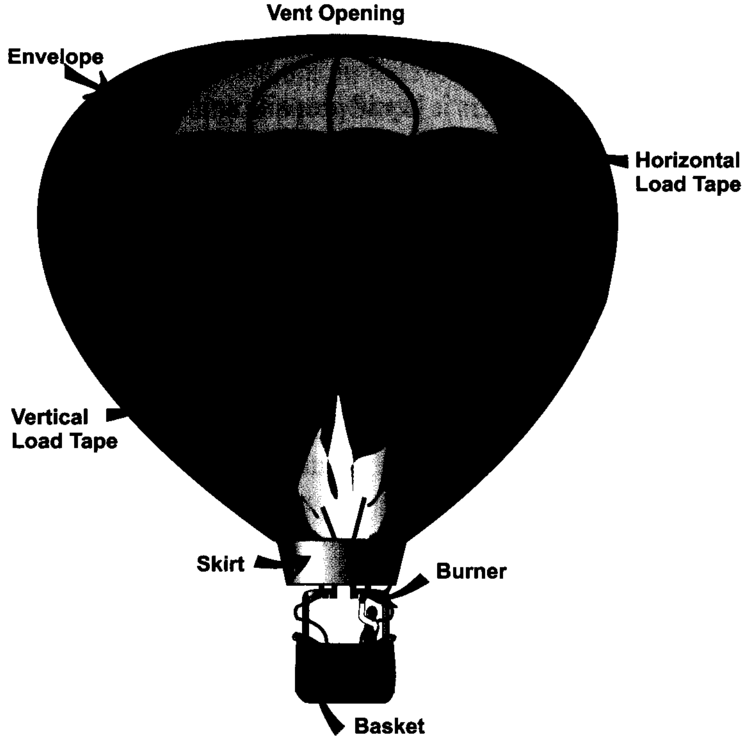
Power for the balloon is provided by a propane burner that quickly heats the air inside the envelope. The propane, in liquid form, is stored in tanks carried in the basket. When the pilot pulls a cord, the liquid propane rushes through a series of vaporizing coils and is ignited at a jet by a pilot flame in the burner. During ascent, it is quite common to have temperatures inside the envelope reach 212° Fahrenheit. To get this kind of heat, burners need to produce several million BTU's/ hour. For clarification, A **BTU** is a "British Thermal Unit" and by definition it is a measure of heat. It is defined as **the amount of heat required to raise the temperature of one pound of water, one degree Fahrenheit.** The metric equivalent of the BTU is a Calorie. A Calorie is the amount of heat required to raise the temperature of one Kilogram of water, one degree Celsius.

A balloon **floats on the wind** and directional control is minimal. At various altitudes, wind direction can change and pilots take advantage of this by climbing or descending to get the balloon to change direction.

The Mathematics Of A Balloon's Lifting Power

In the excellent book, *Ballooning, A Complete Guide To Riding The Winds,* by Dick Wirth and Jerry Young, an explanation is given for the lifting power of a balloon. "Typically, a (hydrogen) gas balloon will derive about 60 lbs. of lift per 1,000 cu. ft., whereas a hot-air model will develop only 17-20 lb. Per 1,000 cu. ft. (at 100-120 degrees Celsius). Thus a 77,000 cu. ft. balloon will lift: 77 x 17 = 1,309 lbs. gross lift. "

The authors state that the envelope will weigh about 160 lbs., the burner and basket will weigh collectively 150 lbs., four gas tanks will weigh 290 lbs., and this gives a total aircraft weight of 600 pounds. If the balloon has a gross lifting power of 1,309 pounds, that means it will carry 709 pounds,



To go up, the pilot lights the burner to create hot air inside the envelope. To descend, the pilot can pull down on the parachute control and this allows hot air to escape out the vent opening.

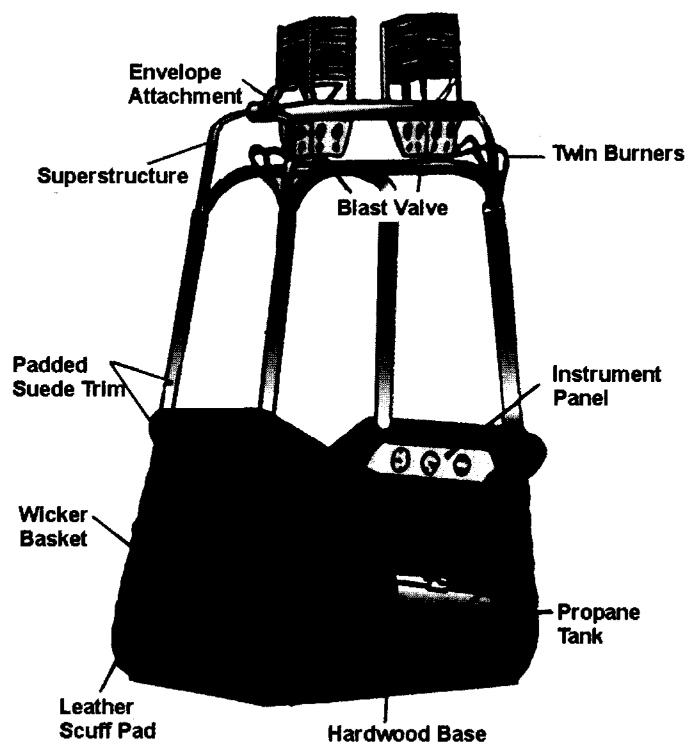
under standard conditions. Divide 709 by the weight of an average human at 170 pounds and the balloon will carry 4.17 persons, or three passengers, one pilot and some miscellaneous equipment.

Construction Of A Balloon's Envelope

A large volume of lightweight air is best contained in a sphere. If you study a hot air balloon closely, you will notice that the general shape of the envelope is spherical. To make the shape of a balloon, a series of panels are sewn together. These panels are called gores. The fabric most widely used is nylon and Dacron, a form of polyester. There are advantages to both of these fabrics. Dacron will withstand higher temperatures, but nylon is lighter and stronger. The fabrics are coated with polyurethane and other additives to give it longer wear and greater resistance to ultraviolet sunlight damage. Most fabrics weigh between 1.2 and 2.4 ounces per square yard. ***(We highly recommend that you try building and flying a hot air balloon kit. They can be ordered from the Civil Air Patrol Supply Depot(1-800-858-4370)***

The Basket - A Balloon Pilot's Cockpit

A balloon pilot's control system is the ascent and descent power of the burner. There is a panel inside of a hot air balloon that allows some of the hot air to escape. It's called a **parachute** and looks somewhat like a conventional parachute only it fills a hole in the top of the balloon. This hole is known as a **vent**. The vent varies from 6-18 feet across. The parachute is held in place by cords inside the envelope. The hot air pressure inside the balloon keeps the parachute in place; however, when the pilot wants to release some of the hot air, a cord is pulled which draws the parachute downward thus opening the vent hole. When the cord is

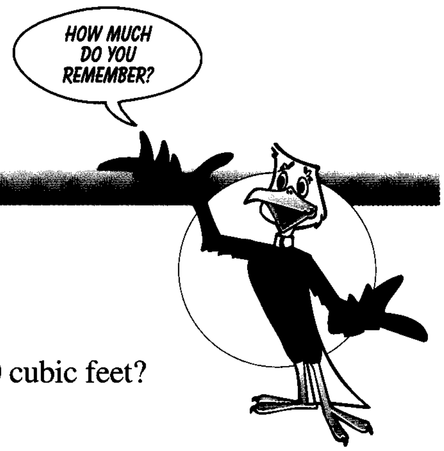


released, the parachute is pushed back into the vent, closing it so the rest of the hot air is not allowed to escape.

The basket of a balloon is its cockpit. The fuel for the burners is liquid propane and is carried along in cylindrical tanks. When the liquid propane passes through the coils on top of the burner, it vaporizes. A small pilot flame ignites the propane and a much larger flame shoots up through the skirt into the envelope.

Cockpit Instrumentation

Generally, the pilot has only three instruments on the instrument panel. One of the most important is the vertical velocity indicator, or variometer This gives the pilot an indication of the rate of climb and descent. Next, the pilot has an instrument that gives a measurement of the temperature at the top of the balloon and it is known as a Thermistor. This is an electronic warning instrument that shows the pilot when the temperature is dropping and a descent is about to occur. The optimum temperature inside the crown is around 100 degrees Celsius. Finally, an altimeter that gives the height of the balloon above sea level.



REVIEW QUESTIONS

1. Hydrogen will lift approximately how many pounds per 1000 cubic feet?
   a. 1000 pounds
   b. 60 pounds
   c. 600 pounds
   d. 20 pounds

2. Hot air will lift approximately how many pounds per 1000 cubic feet?
   a. 1000 pounds
   b. 60 pounds
   c. 600 pounds
   d. 17-20 pounds

3. Directional control of a hot air balloon is obtained by
   a. stabilizers and rudders.
   b. elevators and stabilizers.
   c. flaps.
   d. None of the above are correct.

4. For rapid descent, a balloon pilot pulls down on the ___ and this allows hot air to escape.
   a. burner control
   b. parachute pull cord
   c. vertical load tape
   d. hot air release valve

5. The first, manned hot air balloon ascent was piloted by
   a. the Montgolfier brothers.
   b. the Wright brothers.
   c. Marquis Francois d'Arlandes and Pilatre d'Rozier.
   d. Chuck Yeager.

6. To rise or float is the definition of
   a. inflation.
   b. buoyancy.
   c. thermistor.
   d. Bernoulli.